MORE PROFITABLE HIGH-SCHOOL CHEMISTRY

SCIENCE is usually regarded as the exact and systematic statement of our knowledge of a subject. If we accept this definition, the study of chemistry becomes the acquisition and arrangement of those facts and principles which give adequate expression to this branch of science. The trend of science teaching, in the best high schools, however, is toward a deeper, more liberal and vital conception. To the modern teacher whose work is a potent factor in the problem of education, science is the investigation, interpretation, and comprehension of truth. And the study of a single subject like chemistry is not merely the collecting and classifying of facts, however fruitful that task may be, it is an ardent search for truth.

A decade ago chemistry was taught in high schools almost exclusively by a text-book, supplemented by frequent lectures which were often illustrated more or less by experiments. But as the broader conception of science arose; the verbal method began to be replaced by the laboratory method. Pupils ceased merely to read and listen, and began to work and think. So rapid has been the transition that today in many high schools the major part of the work in chemistry is done in the laboratory.

Experience is gradually showing, however, that no single channel of instruction is applicable to chemistry. Some phases demand one kind of treatment and some another. Often the successful teaching of different parts of the same topic requires widely different methods. It is a fact too often overlooked by a zealous teacher who is provided with a generous equipment that, while many principles may be profitably developed in the laboratory, there are other principles which are actually obscured by experimental treatment.

The natural method of teaching chemistry recognizes the laboratory as the center from which profitable instruction proceeds, as a guiding star for completing a scientific journey, but

not as the whole celestial sphere. This method utilizes the supreme pedagogical value of other factors besides individual laboratory work, *e. g.*, brief lectures, quizzes, numerical problems, essays, excursions, written reviews, and collateral reading. It considers the whole being. It recognizes the sensibility and the will as well as the intellect. It emphasizes the intimate and sympathetic relation of soul, mind, and body.

This method is composite and cannot, therefore, be rigid. The teacher of chemistry should have time enough to secure results which are at least commensurate with the time, money, and energy expended. Statistics gathered by the New England Association of Chemistry Teachers show that the better high schools in Massachusetts devote approximately five periods a week during the school year to chemistry, and this fact is corroborated by data furnished by the State Board of Education. In the judgment of the writer this time is adequate, provided it is placed at the sole disposal of the teacher of chemistry. He should be allowed to use the time allotted to his department as the state of his classes demands. His program should be flexible. That is, he should not be obliged to have a lecture, or a recitation, or a laboratory period at a fixed hour simply because the program in September apparently necessitates this arrangement, nor because another teacher would like his lecture room for unexpected work. The teacher of chemistry ought also to have at least one double period a week. The actual economy of the double period can scarcely be determined. It permits consecutive mental work, avoids troublesome and costly interruptions, allows time for needed rest, calm work and consultation between teacher and pupil. Statistics recently gathered, show that of forty-six high schools in Massachusetts twenty-six had *no* double period for chemistry.

The teacher of chemistry needs reference books. Statistics show a deplorable lack of this species of teaching material. Of forty-two high schools in Massachusetts twenty-four had no distinct chemical library, and with few exceptions the collection of books in the remaining schools was meager. Reference books are essential in studying chemistry. All facts are not recorded

in a single small book. Indeed, certain facts should not be in the book used by the pupil. Lists[1] of suitable reference books are available, and ten dollars will purchase several helpful books, to which more may be easily added each year.

Finally the teacher of chemistry needs more leisure time. It is a mistaken idea that a laboratory teacher is not working unless he has a class before him every minute. A chemistry teacher of all others needs time to arrange the workshop of his class, time to consult with individual pupils, time to repair, clean, arrange, and replace apparatus, time to clean up what pupils and janitors will not do, time to mix solutions, put them in properly labeled bottles, and the bottles in the customary place, time to correct laboratory notes and see that the pupils understand the corrections, time to arrange lecture experiments and remove the unsightly results before the room is again used, time to visit with classes the neighboring shops and manufactories which illustrate the industrial phases of chemistry, time to read current scientific literature, time to *rest* physically and mentally so that he may come daily to his classes with that mental poise which is essential to successful teaching.

The source of profitable instruction in chemistry is undoubtedly the experimental work of the pupil. But the psychology of experimental science has not been adequately studied. I may be pardoned then if I briefly discuss from a psychological standpoint the natural or composite method, above mentioned in its relation to "more profitable high-school chemistry."

Laboratory work is concrete labor. A laboratory is a workshop, where a pupil must use his hands as well as his head. It is a place where there may be a harmonious combination of mental and manual labor. Now such work cannot be shirked mentally. In studying mathematics, especially geometry, the mind easily wanders. The case is the same with history, and so much so that the present methods of teaching history are largely those used in the laboratory. But when the mind is following an experiment in the laboratory, it cannot shirk. Something is

[1] The L. E. Knott Apparatus Co., 16 Ashburton Place, Boston, Mass., will send such a list on request.

constantly happening; the mind is carried quickly from concrete to concrete. Various instruments must be arranged, materials collected, operations started, watched, controlled and stopped. Things must be seen and done. The laziest mind must think of something; it may not be the most important thing, but it must think.

Again, laboratory work relieves mental fatigue. Pupils in most of our high schools are crowded with purely mental work. They are under a constant mental strain. Many are unconscious victims of a disease rightly called brain fatigue, not because they have used their brains too much, but too long on the same kind of mental work. Laboratory work is restful, not merely because it provides an interesting change from books, but because the eyes, hands, nose, in fact all parts of the body are in harmonious action. No part is pulling another. There is a minimum amount of tension. Each organ bears a share of the nervous burden. Harmonious action is freedom. Cheerful, interesting work is the remedy for fatigue.

Laboratory work produces the highest grade of reactive conduct. Reception is followed by reaction, and impression produces a corresponding expression. Teachers are apt to forget that the natural outcome of thought is action, that knowledge is incomplete without action, that all motor activities are the expressions of thought. Expression is necessary to life. The mind grows through the exercise of its faculties, just as a muscle grows through its use.

It is no wonder that in many high schools chemistry is not more profitable. If the teacher of chemistry or the principal does not favor laboratory work, if the teacher persists in explaining in the class room what the pupil can think out in the laboratory from his own data, if the program restricts the laboratory work to a pitiable minimum, then it is folly to expect the course to yield mental results. There must be enough laboratory work to teach the mind not to shirk. Heads cannot learn to work in continuous sympathy with hands, if hands have little or nothing to do. If, on the other hand, most of the work must be done in the laboratory and very little time for various reasons can be

devoted to the subject outside the laboratory, then the pupil likewise suffers a distinct mental loss. His experimental results receive no mental stimulus and are soon forgotten. Laboratory results to be profitable must be driven home by searching questions, brief lectures, written reviews, and numerical problems. The work should be so conducted that pupils cannot truthfully say, as a boy once said regarding his work in physics: "Oh, we just measure, that's all."

Again, if the double period of laboratory work is too long, if there is no opportunity for pupils to sit down in the laboratory to write notes, consult reference books, or perform slow experiments, if the directions for performing the experiments are so vague, or brief, or long that their interpretation requires excessive mental energy, then mental fatigue will be increased, not neutralized. The laboratory will not afford that mental rest which it is designed to provide, and possibly both mind and body may refuse to act normally.

Finally, if the laboratory work is inadequately supervised owing to large divisions, program restrictions, or pedagogical inefficiency, then the reactive conduct will be of a low, perhaps the lowest, grade. The pupil who is called upon to be doing something constantly should be stimulated by an environment which will permit him to do the right thing. Good expression cannot come from bad or meager impressions. Teachers of chemistry who are content to let the laboratory run itself, who see no psychical need of helping a confused pupil to regain his mental poise, who do not constantly realize that beginners are as prone to believe error as truth—such teachers are unprofitable servants of the science of chemistry. A magnificent pedagogical opportunity awaits those teachers who believe that it is their personal contact with pupils working in the laboratory under favorable conditions which begets good habits of observation, teaches the difference between accuracy and vagueness, inspires a belief in the utter inadequacy of all abstract verbal accounts of real phenomena, increases mental self-reliance and independence, inculcates honesty in little things, and shows that harmonious action of head and hand is mental rest.

The interrelation of curiosity, interest and attention has an important bearing on instruction in chemistry. Pupils see little value in distasteful studies. Indeed, for them, such studies have no mental value, if the dislike continues. Beyond question there are times when pupils should be made curious. Psychologically, they should receive impulses toward better cognition. But curiosity is like a newly-driven oil-well. Its treasures often burst suddenly into the air as soon as the drill pierces the crust and are lost unless the skillful master is at hand to gather and ultimately refine the crude product. At best curiosity is an unscientific stimulus. It may serve a purpose, but it can never control the stream it bridges. The problem is to lead pupils from indiscriminate curiosity in things to a philosophic grasp of principles, from pleasure in mere observation of striking facts to esthetic contemplation of the truth. The thoughtful teacher of chemistry arouses this dormant, unbridled curiosity by using short, striking experiments, stimulates it by interesting information, by collateral reading, by excursions to museums and shops, or by simple numerical problems, and thereby leads the pupil to act from rationalized curiosity, that is, from normal interest.

The transition from curiosity to interest is a crucial test for the pupil and a critical time for the teacher. The passage is sometimes imperceptible, alas, to both teacher and pupil. Some pupils never pass from curiosity to interest. Too often, a thoughtless word, an unintentional but definite oversight, an inexcusably flippant attitude on the teacher's part may upset the delicate poise of the pupil's mind and turn to permanent indifference what might have become lifelong interest. This may be true of all subjects, but it is especially true of chemistry, since the teacher and pupil are closely associated in the laboratory and the work by its very nature demands continued consultation. Pupils must be studied as units, their complete mental life should be known, and just before they reach the parting of the ways, as they do day after day, the teacher should never fail to point them unerringly into that path best adapted to their total development.

Chemistry is admirably suited to rationalize curiosity, and

thereby lead the pupil to act from philosophic interest. Disconnected observations may be easily correlated, examined, tested, and judged by the pupil. The field is spread before him, seed is provided, and it remains for pupil and teacher to plant the seed, nurture it, and gather the ripened product. Laboratory work supervised from the broadest standpoints will lead pupils to abandon insidious self-indulgence in merely observing and induce them to act from scientific insight, critical testing and personal conviction.

There are two kinds or grades of interest, native and acquired. Most pupils have both, delicately mingled, though often latent. Native interest is not always focused on the most helpful subjects, hence pupils should be urged, perhaps indirectly compelled, to study those subjects which foster the growth of acquired interest. They should be induced to associate subjects that are primarily uninteresting with other subjects in which interest already exists. The most fruitful fields of study are those which not only educe native interest but also create acquired interest. Chemistry is preëminently fitted to arouse native interest. It presents at the outset work which invokes examination, explains natural phenomena, and answers questions about common things. This is especially true in the application of chemistry to many industrial operations, to medicine, to certain phases of photography and voltaic electricity, to the composition of rocks and minerals, to the constituents of the atmosphere and to the properties of acids and alkalies. But chemistry should not stop here. To be intellectually profitable, it should lead the pupil to acquire an interest in the laws underlying these natively interesting topics. That is, an opportunity should be provided to study the phenomena from the causal standpoint, to generalize from observed facts, to read the historical setting of the discovery and growth of the apparently new observations and to fix permanently in mind any mathematical transformations involved in the chemical changes.

Interest is inevitably accompanied by attention. A natively interesting object arouses passive attention, that is, attention requiring no deliberate, conscious effort. It is often called

involuntary attention, and is the more common kind. Indeed, some pupils seldom pass beyond this mental stage. They never will to think. They are mere passive recipients. It is doubtless true that many pupils are mentally suspended. Their native interests are pampered so long that they become unfitted for much mental work beyond passive or desultory observation. It is voluntary attention which is essential to complete psychical life. We must will to think, if we are to live. Professor Ladd says: "What I will to think becomes interesting and attracts further attention to itself." Voluntary attention is really a momentary act. The total time consumed by voluntary attention in most of our mental lives is short, but its importance in the attainment of knowledge is almost incalculable. It wheels the forces of the mind into line, and then the passive attention leads them along until another voluntary act is necessary, and so on. Pupils need to see the value of voluntary attention, the inestimable value of being able to complete with success an experiment requiring skill, patience, and confidence. No means, even the simplest and apparently the most insignificant, should be spared to arouse voluntary attention. There is a class of experiments in chemistry which simultaneously demands and cultivates voluntary attention. I refer to quantitative work. The judicious introduction of experiments involving exact weighing and measuring will make a course in high-school chemistry more profitable. Consider, for example, the determination of the weight of a liter of oxygen. A test tube containing a mixture of manganese dioxide and potassium chlorate is attached by a sickle-shaped tube to a large bottle filled with water; a delivery tube passes from the bottom of this bottle into an empty bottle. The test tube and the empty bottle are weighed before and after the operation. If the test tube is heated, oxygen passes into the full bottle and forces water over into the empty bottle. The loss in weight of the test tube is the weight of the liberated oxygen, the gain in weight of the catch bottle is equivalent to the volume of oxygen. From these two results the weight of a liter of oxygen is easily calculated. This experiment is absorbingly interesting. The water falls in

one bottle and rises in the other throughout the heating, and the mixture in the test tube changes in color and consistency. Moreover, the whole operation, exclusive of calculations, requires only about half an hour. But it arouses curiosity, stimulates native and acquired interests, and demands voluntary attention. It covers the whole psychology of laboratory work. In no case where this experiment has been done in the writer's laboratory has there been the slightest lack of interest or attention. Furthermore, the arithmetical computations, which are somewhat complicated, are willingly worked out, because pupils are voluntarily interested in the final result; they want to know just how much their liter of oxygen weighs. And it may be said in passing that the results are uniformly accurate—the class average varying only a few hundredths of a gram from the theoretical value. If, on the other hand, the pupil is finding the ratio in which magnesium and oxygen combine, his attention may flag, because this experiment has uninteresting stages. In other words, it demands too continuous voluntary attention, so much, in fact, that in some cases it has proved beneficial to allow the pupil to perform simultaneously other and more interesting experiments. Nevertheless this experiment furnishes valuable training. After a few quantitative experiments have been performed, the importance of such work becomes apparent not only in similar experiments, but also in the general laboratory work. It simply means that exact work cultivates voluntary attention. In other words, it teaches mental self-reliance, activity and accuracy. Again, exact experiments lead naturally to fundamental laws, hence the results of laboratory work furnish a sound and attractive basis for the discussion of chemical theory. They likewise give zest and interest to the often unwelcome task of solving numerical problems, since the problems can be based on the experiments. I regard simple quantitative work as a most fruitful field for teachers of chemistry to cultivate. It is true such experiments require a modern book and adequate apparatus, but these essentials are available at a cost which is much less than would be suspected. The mental results of exact experiments are produced by careful, patient, sympathetic,

inspiring supervision of each pupil's total work. Such teaching takes time, but no more time than any effective teaching.

It was thought about half a century ago that certain nerves checked the action of certain muscles. This is true, but it is a narrow interpretation of a more general function of the nervous system. This conception of arrest, as it is often designated, has been extended to cover our mental life, irrespective of nerve stimulus as such, and is called inhibition. It is not necessary that an inhibiting idea be especially strong, for here, as elsewhere, the mental machinery is delicately constructed. A strong motor idea may be easily and completely inhibited by a simple and apparently foreign idea. Faint impressions on the confines of consciousness may throw the strongest idea entirely off the track. Some trivial observation may upset a thought which is seeking expression, and either arrest it completely or so modify it that the final judgment is delayed, or suspended, or even hopelessly abandoned. Obviously, pupils need to be prevented not only from purely impulsive action on one hand but also from cowardly inaction on the other. They should not be allowed to yield to unwarranted inhibitions, but should be constantly urged to rational mental action.

Chemistry provides a grand opportunity to train the mind to be judicial, to consider calmly, deliberately and persistently Day after day conditions arise in the laboratory which spread before the pupil's mind the whole field of consciousness upon which decisions must be based. He must not only observe phenomena, he must also interpret them. Moreover, his conclusions are rigorously tested, and hence he soon realizes that observations must be accurate and complete, and that conclusions must be honestly made. Experience, dearly bought, tells him with unerring voice not to yield to reckless impulse or foolish inhibition.

If chemistry is to be profitable, it is obvious that experimental work should be so conducted that the mind can travel without many inhibitions from the object of the experiment through the manipulation to the conclusion. It is a deplorable fact that many books in chemistry now in use absolutely ignore these

fundamental psychological principles. Some books deliberately tell the result of the observation before the pupil has an opportunity to observe. A few scorn experiments with titles. Consequently there is nothing to indicate the relation of experiments which constitute a unit; the beginner is not even started on the right mental track. Others inject needless, incongruous questions into the midst of the directions for manipulation. And some even introduce topics which should seldom, if ever, be considered out of the class room. A favorite topic of this sort is the equation. In many books the text too often tells the whole story. It is, to be sure, almost impossible to avoid telling something in a combination of text and experiment, but the less told the better. Again, most of the books fail to carry the experimental results to a definite end. The student is left suspended, he is robbed of an inestimable mental exercise, to say nothing of being compelled gradually to lose serviceable information. Moreover, some of the books, especially some which are often quoted, are too easy for both teacher and pupil. It is a temptation, especially to a busy teacher, to use a book which "runs itself." Such a lapse of good faith takes little or no time, the pupils make no complaint, and the results are apparently permanent; indeed, much information seems to have been gained by the pupil. It is doubtless true that the average pupil does accumulate a few isolated facts, but at what a tremendous mental expense! The mind is pointed to no introductory guiding star, to no suggestion which will lead it from mere curiosity to fruitful interest and finally to voluntary interest. Worst of all, the mind is prevented by numerous insidious inhibitions from acting calmly, continuously and logically. If experiments are to be profitable, they should be so expressed and arranged that the average pupil cannot fail to grasp at least the title, the exact method of procedure, the essential observations to be made, and the probable conclusion which such observations will permit. The directions must be specific, complete, and accurate. Skillfully worded questions will educe the desired observations, but such questions should not be inserted where they will seriously interrupt the continuity of the thought. Books constructed on

these conceptions are rare, but enough exist to render our high-school chemistry more profitable, if they are used with an honest determination to educate the pupil.

It is not too strong to say that the real educational value of chemistry is largely conditioned by the mental equipment of the teacher. His problem contains two unknown but determinable quantities—himself and his pupils. Success depends upon the teacher's knowledge of his own psychological and spiritual life, as well as upon the discovery of mental crises in his pupils. He must create an atmosphere which fosters calm, deliberate, confident, untrammeled mental ability. Each day, as he lives with the souls who come to him for inspiration, his one purpose, shining brightly in the midst of the toil, the routine and the incessant effort, should be to lead them to investigate, interpret, and comprehend the truth. He must be the truth, for "what we are shall teach."

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